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SPACE SHUTTLE ENTRY ENVIRONMENT TESTING TECHNIQUES

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ABSTRACT

Testing techniques have been developed for simulating the high temperature portion of the entry environment which have been applied to testing large Space Shuttle leading edge structural segments. The test techniques involve the use of arrays of graphite heating elements which radiate heat to the test articles.

INTRODUCTION

Development of materials for the Space Shuttle leading edge structure requires new testing techniques which can be used to evaluate the performance of these materials in their specific operating environments. The type of materials being addressed in this paper are the non-metallic composites which are baselined for use on the Shuttle wing leading edge, nose cap, and belly panels. Figure 1 identifies the location of the special leading edge materials on a proposed Space Shuttle configuration. A close view of a typical wing segment of the leading edge is shown in Figure 2. Other shapes of segments will be used on the belly and nose portions of the Shuttle vehicle.

These materials will be exposed to temperatures up to $3000^{\circ}F$ in an oxidizing environment during entry of the Space Shuttle vehicle from earth orbit. The standard test technique which was used for baseline evaluation of small specimens was plasma arc exposure. The plasma arc provides a relatively good simulation of the entry environment when considering the desired entry gas temperature, composition, pressure and enthalpy but generally have a severe limitation in the size and geometry of specimen that can be tested. For example the largest plasma arc specimens (with a few exceptions) that were tested in LTV's development work were simple 3" diameter discs using a 10 megawatt plasma arc facility at Johnson Space Center. Because of the specimen size limitation, new test equipment was designed to test a wider variety of specimen

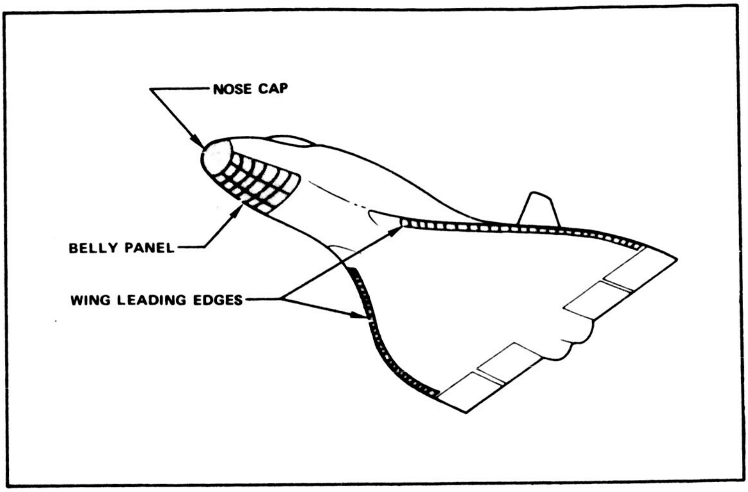


Fig. 1 – Location of Leading Edge Materials on Proposed Space Shuttle Configuration

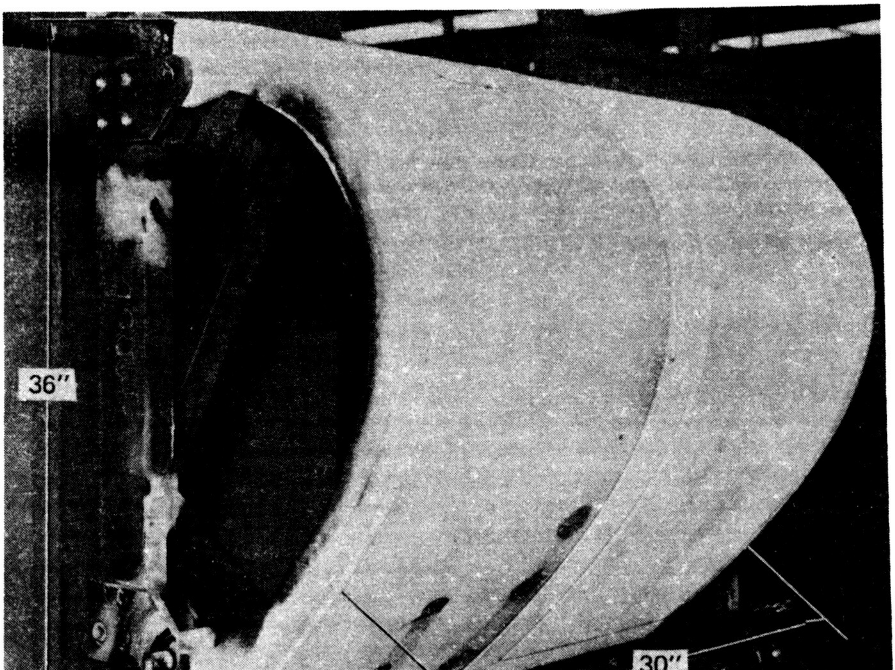


Fig. 2 – Shuttle Wing Leading Edge Test Article

sizes and geometries.

Two categories of test specimens were required by the materials development specialists at LTV. The first category was a large batch of physical property specimens (tensile, compression and flexure) from which statistical data could be obtained for correlation to the number of exposures to a simulated entry environment. Typical shapes of this type of specimen are shown in Figure 3. The second category of specimens were full size leading edge segments similar to that shown in Figure 2.

The entry environmental parameters are shown in Figures 4 through 9. The work being reported in this paper involves the exposure of test specimens to the temperature and atmosphere environmental parameters illustrated in Figure 6, 8 and 9. A considerable amount of work has been done in other areas of testing but is not being reported in this paper. The effects of temperature and an oxidizing atmosphere on the leading edge material were considered the most critical aspect of the leading edge design.

HARDWARE APPROACH

It was decided to expose batches of physical property specimens to the combined oxidation temperature environment and restrict the full scale testing to the temperature environment in an inert atmosphere. Another ground rule was that the physical property specimen would be exposed to at least 100 cycles of the combined environment. Each cycle was designed to simulate one entry mission. During the course of 100 combined environment cycles a statistical sampling of flexure, tensile and compression specimens was removed from the heating fixture every 20 cycles. These specimens were to be tested to failure in order to evaluate physical property degradation as a function of the number of mission cycles.

Two test setups were planned. The first setup was to satisfy the multicycle combined environment requirement for small specimens and the second setup was to provide the entry temperature environment for a full scale test article segment.

HARDWARE DESIGN

For the combined environment test a fixture was designed as shown schematically in Figure 10 consisting of a vacuum

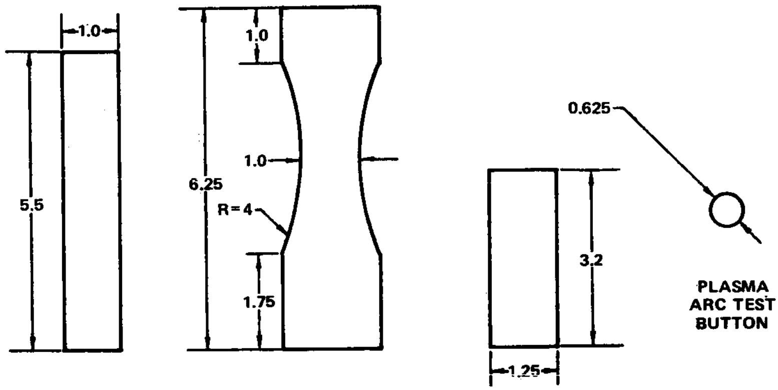
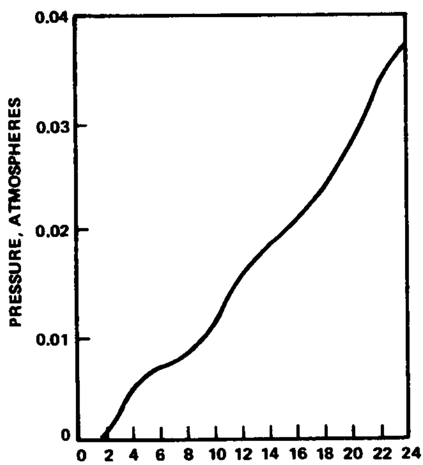
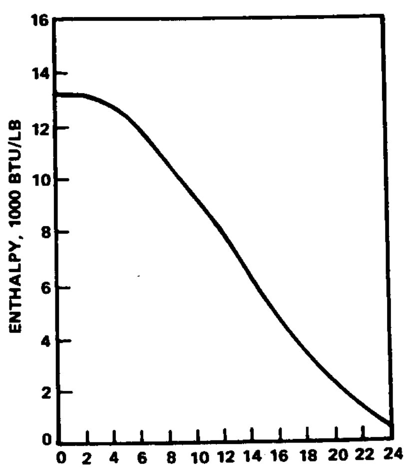


Fig. 3 — Physical Property Test Specimens





ENTRY TIME, 100 SECONDS

Fig. 4 — Stagnation Pressure

Fig. 5 — Total Enthalpy

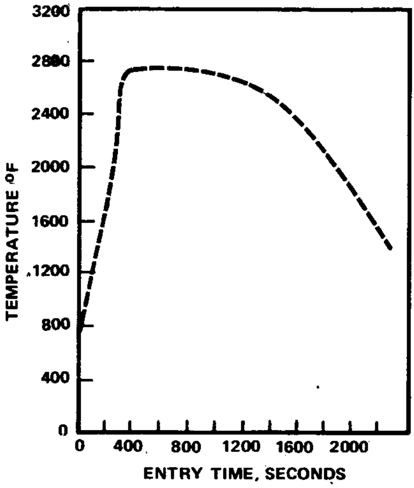


Fig. 6 — Leading Edge Temperature

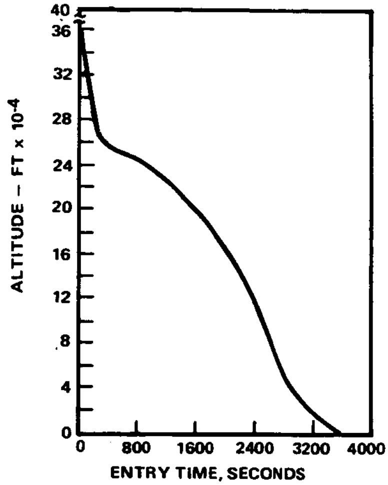


Fig 7. — Mission Altitude

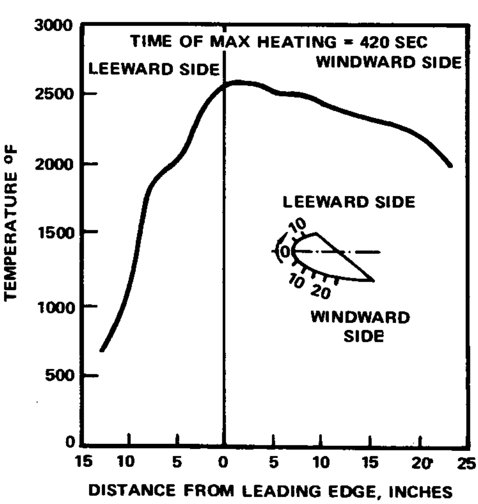


Fig. 8 — Temperature Distribution Around a Leading Edge Segment

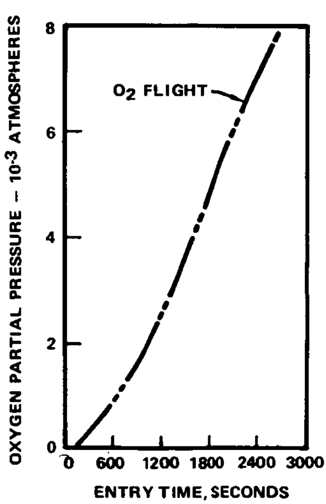


Fig. 9 — Oxygen Partial Pressure

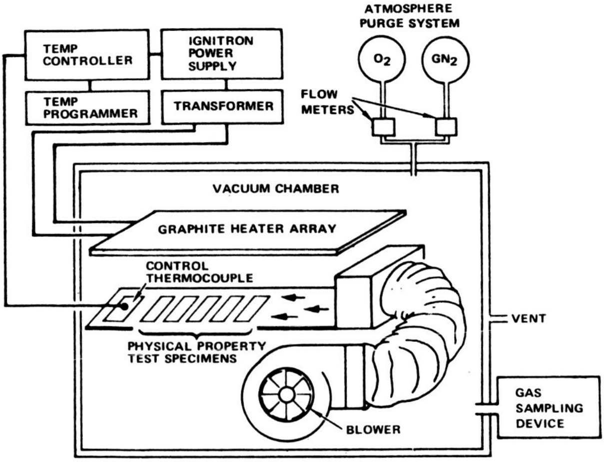


Fig. 10 – Diagram of Combined Environment Test Equipment

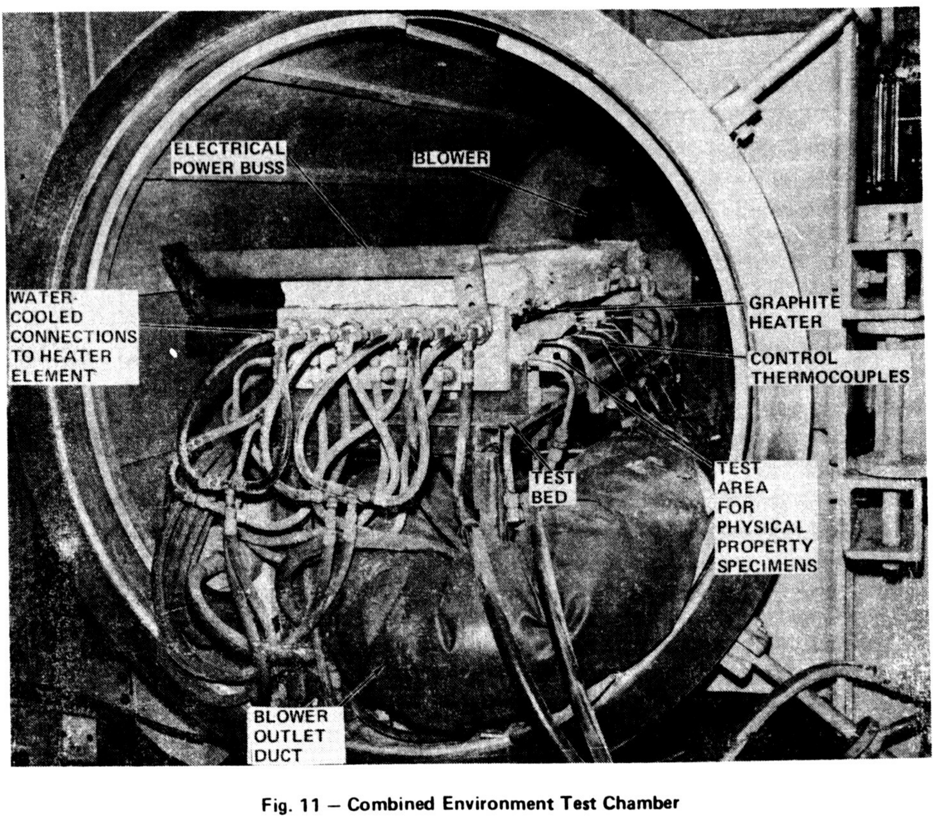


Fig. 11 – Combined Environment Test Chamber

chamber, radiant heater array, power supplies, gas circulating system, and a gas purging system. Figure 11 is a photograph of the actual setup. The vacuum chamber was 4 feet in diameter by 8 feet long with necessary ports and feedthroughs for power, cooling water, gas, and instrumentation. The heater elements were machined from graphite rods into a configuration as shown in Figure 12. A common heater element design was selected for use on both the combined environment and the temperature environment test fixtures. For the combined environment fixture, seven heater elements were connected in series to the output of a 150 KW, 120 volt secondary single phase transformer. This arrangement provided a test area of approximately two square feet in which up to 75 specimens could be exposed at one time. A threaded water cooled aluminum electrode was designed which attached to the end of each heater element. Copper bus bars were used as both electrical power connectors and structural supports to join the heater elements. Tungsten-5% Rhenium/ Tungsten-26% Rhenium thermocouple assemblies were used as temperature sensors for the temperature control arrangement shown in Figure 10. The temperature programmer provided the temperature profile shown in Figure 16. Additional thermocouples were located in various specimens throughout the test area.

In order to test the full scale leading edge segment shown in Figure 2, a test fixture was designed as shown schematically in Figure 13. The fixture consisted of a vacuum chamber, radiant heater array and a power supply system. The LTV Space Environment Simulator chamber, which is 12 feet in diameter, was used for the vacuum chamber. The graphite heating elements described above were assembled in a contoured manner as shown in Figure 14.

The heating elements were divided into four zones which could be individually controlled in order to produce the temperature gradiants shown in Figure 8.

Figure 15 is a photograph of the actual setup showing the leading edge segment partially raised out of the insulated heating array assembly. The total assembly is shown mounted inside the vacuum chamber. Thermocouple assemblies can be seen attached to the various surfaces of the leading edge segment. A steel mounting fixture, which simulated the structural interface between the leading edge and the Shuttle wing, was provided onto which the segment was attached with pin connections at six locations. One of the attachment points can be seen in Figure 15. The heater array was powered by use of four individually controlled power circuits as illustrated in Figure 13.

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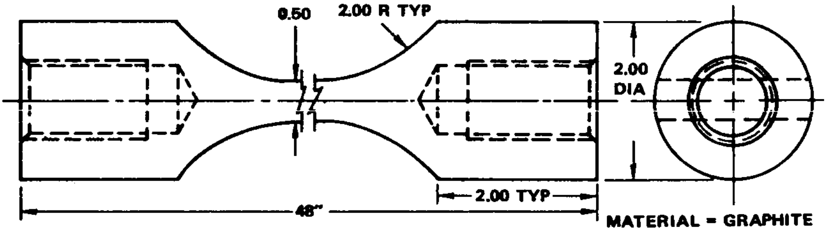

Fig. 12 – Graphite Heating Element

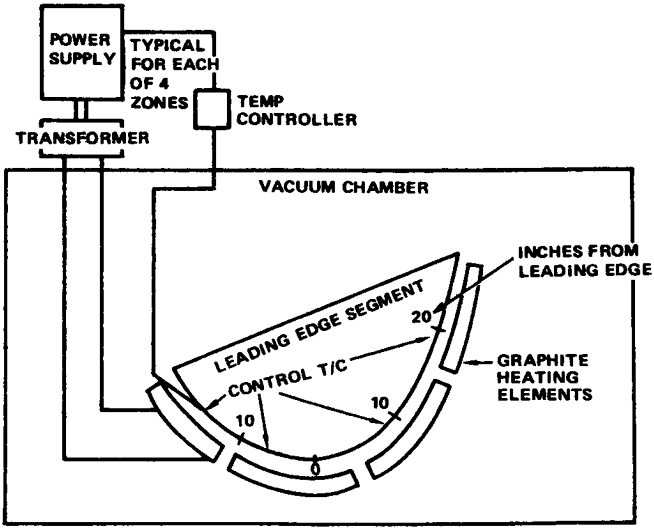

Fig. 13 – Full Scale Test Arrangement

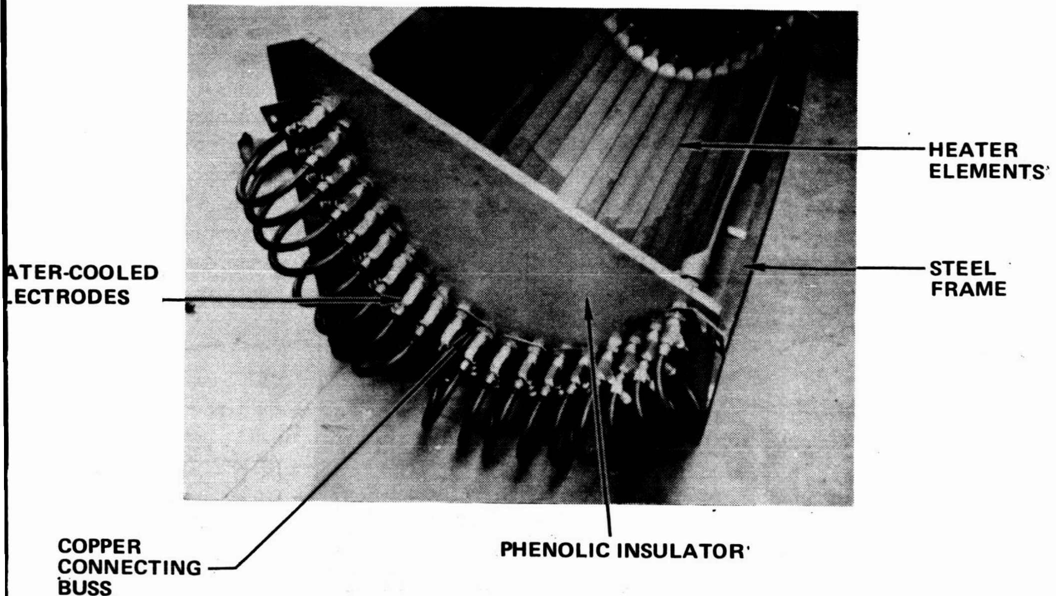

Fig. 14 – High Temperature Entry Test Fixture

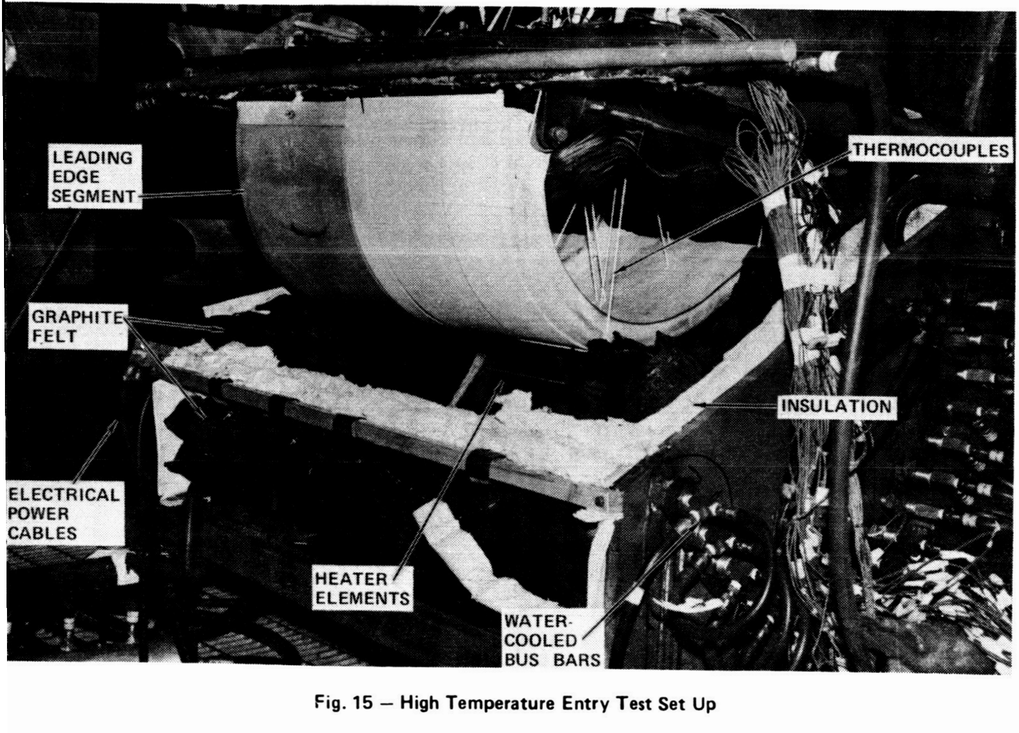

Fig. 15 – High Temperature Entry Test Set Up

The gas purge system provided a 3 psig mixture of nitrogen and oxygen simulating an average oxygen partial pressure level which would occur during the high temperature portion of the entry environment. The blower and duct arrangement provided a continual circulation of the chamber atmosphere across the exposed face of the specimens at a velocity of approximately twenty feet per second. The oxygen partial pressure was monitored by periodically drawing samples from the chamber and measuring the oxygen content on a gas chromatograph.

TEST PROCEDURE AND RESULTS

The combined environment test fixture was calibrated for temperature by conducting trial runs and measuring the temperature of sample test specimens with thermocouples. The desired oxidizing rate for a given temperature cycle was established as that rate which would cause a specimen weight loss comparable to the rate which would occur during exposure to a specimen button to a plasma arc simulation of the entry environment. The combined environment oxidation rate was determined experimentally through trial runs. The heating area was then loaded with an assortment of physical property specimens. A total of 100 entry cycles were performed. The average temperature versus time and oxygen partial pressure versus time data are shown in Figure 16.

For the full scale temperature environment test the leading edge segment shown in Figure 15 was exposed to an entry temperature profile in an inert atmosphere at a chamber pressure of 10 torr. The resulting temperature data are shown on Figures 17 and 18.

CONCLUSIONS

The above described tests represented a first step toward developing techniques for testing large space vehicle structures in a high temperature entry environment. They were not accomplished without difficulty and considerable improvements need to be made in order to achieve reliable and repeatable test results.

By far the most difficult task was to design the combined oxidation-high temperature test fixture. The selection of oxidation resistant insulations, specimen holding materials and heating elements for long duration testing is quite limited.

Development efforts are continuing to improve upon the testing techniques from both the standpoint of the quality of the test environment and the size of articles that can be handled.

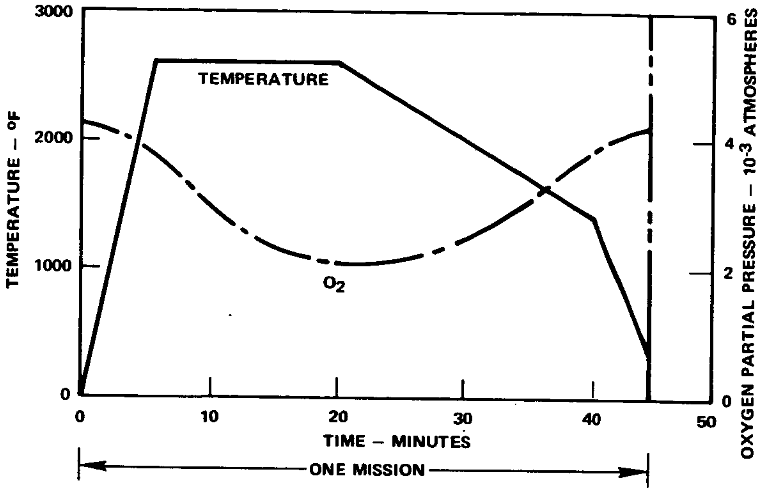

Fig. 16 – Thermal/Oxidation Test Environment

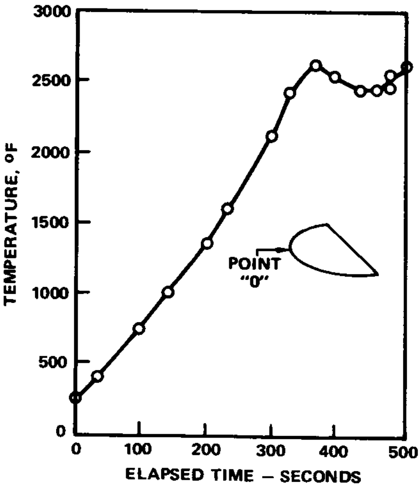

Fig. 17 – Actual Test Temperature at Point "0"

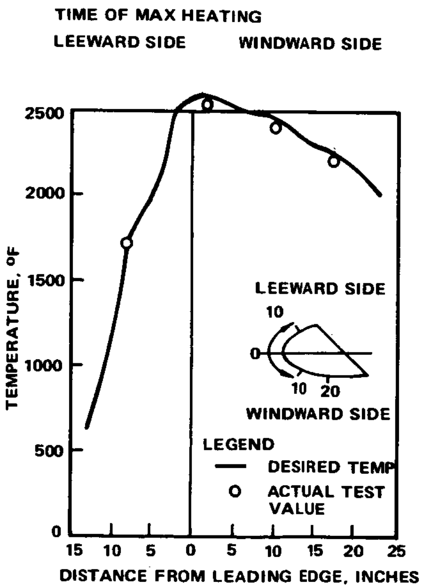

Fig. 18 – Actual Temperature Distribution Around Leading Edge